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# The Ionosphere and Its Effect on the Propagation of Radio Waves

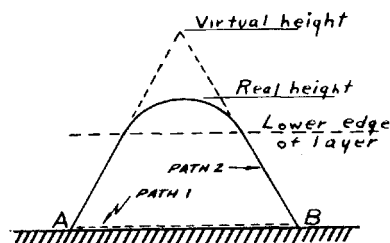
By HENRY WEISZ, E E IV

RADIO waves consist of condensations and rarefactions of energy traveling through space with the speed of light (186,000 miles or 300,000 meters per second). These waves are electromagnetic waves, consisting of traveling electrostatic and electromgnetic fields so related to each other that the energy is evenly divided between the two, and with the lines of force in the two fields at right angles to each other in a plane perpendicular to the direction of propagation.

Like light waves, radio waves can have a definite polarization. The polarization of a radio wave is taken as the direction of the lines of force in the electrostatic field. If the direction of the electrostatic component is perpendicular to the earth the wave is said to be vertically polarized, while if the electrostatic component is parallel to the earth the wave is horizontally polarized. The orientation of the electrostatic component is determined by the orientation of the radiator itself, as the electromagnetic component is always at right angles to a linear radiator, and the electrostatic component is always in the same plane as the radiator.

A simple transmitting antenna or radiating system sends out radio waves in nearly all directions, though the strength of the waves may be greater in certain directions, and at certain angles above the earth. A radiated wave consists of three separate major components in the most general case, a ground wave, a sky wave (also called an ionospheric wave), and a tropospheric wave. The ground wave is the portion of a radio wave that is propagated through space and is, ordin-

arily, affected by the presence of the ground. The sky wave is the part of a radio wave that has been directed toward, or reflected from the ionosphere. The tropospheric wave is any part of a radio wave that has been reflected from a place of abrupt



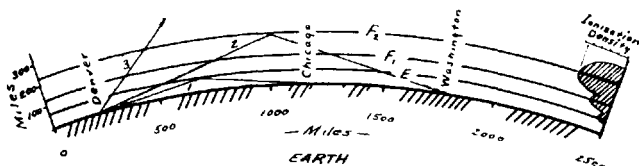
—Courtesy Missouri Shamrock.

**Fig. 2—A wave transmitted at A and received at b is refracted by the layer. This refracted wave may be out of phase with a direct wave from A and cause cancellation of the received signal. A slight changing of layer height would cause waves at B to shift in and out of phase, causing fading**

change of dielectric constant in the troposphere (such as the boundary between hot and cold layers).

The ionosphere, or the Kennelly-Heavyside layer, is the ionized region that exists in the upper atmosphere, and extends from a lower limit of 50 to 80 kilometers, upward as far as possible as 1200 kilometers or as far as there is atmosphere to be ionized. Ultraviolet radiation from the sun is considered to be responsible for the ionization, but the processes by which it is produced and maintained is obscured by the lack of precise knowledge of the composition, temperature, etc., of the atmosphere at the levels involved. It is known, however, that the atmospheric pressure in the ionosphere is extremely small, being little if any greater than that often found in a vacuum tube. Because of this, collisions between electrons and ions are relatively infrequent even in the lower part of the ionosphere; so recombination takes place only very slowly.

The ionosphere is not a single region but consists of a series of "layers" which occur at different heights, each layer consisting of a central region of ionization which tapers off in intensity both above and below. The amount of bending



—Courtesy Missouri Shamrock.

**Fig. 1—Waves 1 and 2 are being reflected by the E and F-2 layers respectively. Wave 3, due to its high angle of incidence, penetrates all layers. This causes a "dead" spot between Denver and Chicago, since no waves are reflected in this range**

which the sky wave undergoes depends upon its frequency, and the amount of ionization in the ionosphere, which is in turn dependent upon radiation from the sun. The sun increases the density of the ionosphere layers, and lowers their effective height. For this reason, radio waves act very differently at different times of the day, and at different times of the year.

For a given intensity of ionization, the amount of refraction becomes less as the frequency of the wave becomes higher (shorter wavelength). The bending therefore is smaller at high than at low frequencies, and if the frequency is raised above a certain value, known as the critical frequency, the bending will eventually become too slight to bring the wave back to earth, even when it enters the ionosphere at a very small angle to the "edge" of the ionized zone. At this frequency (about 45,000 kilocycles) and higher frequencies long-distance communication becomes impossible, although, under exceptional circumstances, radio waves of 75,000 kilocycles have been known to return to earth for very short periods of time.

Although a layer is a region of considerable depth it is convenient to assign to it a definite height, called virtual height. The virtual height is the height from which a pure reflection would give the same effect as the refraction which actually takes place. A wave traveling upward is bent back over a path having appreciable radius of turning, and a measurable interval of time is consumed in the turning process. The virtual height is the height of a triangle having equal sides of a total length equivalent to the time taken for the wave to travel from one point on the earth's surface to another.

There are two layers in the ionosphere having a permanent existence. The layer is termed the E layer; the upper is designated by F at night and  $F_2$  in the daytime. In the day there is also usually an intermediate layer, the  $F_1$  layer, that appears in the early morning, persists throughout the day, and then fades out at night. Other layers have been reported by some investigators, of which the most important is the D layer, which lies below the E layer at a height of about 60 kilometers and probably has an influence on daytime broadcast signals at considerable distances. Very little is known about these other layers, beyond the fact that they are present only part of the time and are much less important than the E and F layers in returning the radio waves to earth.

The distance from the transmitter to where the first sky wave returns is termed skip distance, and, inasmuch as the ground wave is ordinarily absorbed within a few miles of the transmitter, this skip distance represents a region where the

signals are very weak or non-existent, i. e., the waves skip over this territory to return at greater distances. Increasing the frequency still further increases the skip distance because now only those waves entering the layer with relatively glancing incidence are returned to earth.

The lower the angle of radiation of the wave, with respect to the horizon, the farther away will the wave return to earth, and the greater the skip distance. The wave can be reflected back up into the ionosphere by the earth, and then be reflected back down again, causing a second skip distance area; thus multiple reflections are possible. When the receiver receives signals which have traveled over more than one path between the transmitter and the receiver, the signal impulses will not all arrive at the same instant, as they do not all travel the same distance. When two or more signals arrive in the same phase at the receiving antenna, the resulting signal in the receiver will be quite loud. On the other hand, if the signals arrive 180 degrees out of phase, so they tend to neutralize each other, the received signal will drop,—perhaps to zero, if perfect neutralization occurs. This explains why high-frequencies fade in and out.

Selective fading affects all modulated signals. A modulated signal is not a single frequency signal, but consists of a narrow band of waves perhaps 15 kilocycles wide. It will be seen that the whole modulated signal band may not be neutralized at any instant, but only part of it. Likewise, most of the carrier may be suppressed, or one side band may be attenuated more than the other. This causes a peculiar and changing form of audio distortion at the receiver, which is known as selective fading.

Fading can be greatly reduced on the high frequencies by using a transmitting antenna with sharp vertical directivity, thus cutting down the number of multiple paths of signal arrival. A receiving antenna with similar characteristics (sharp vertical directivity) will further reduce fading. It is desirable, when using antennas with sharp vertical directivity, to use the lowest vertical angle consistent with good signal strength for the frequency used. This cuts down the number of hops the signal has to make to reach the receiver, and consequently reduces the chance for arrival via different paths.

For a certain frequency, ionosphere height, and transmitting distance there is an optimum angle with the horizon at which the radio wave should be propagated. For extremely long distance communication, the angle of radiation should be low (5 to 15 degrees above the horizon), regardless of

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## IONOSPHERE

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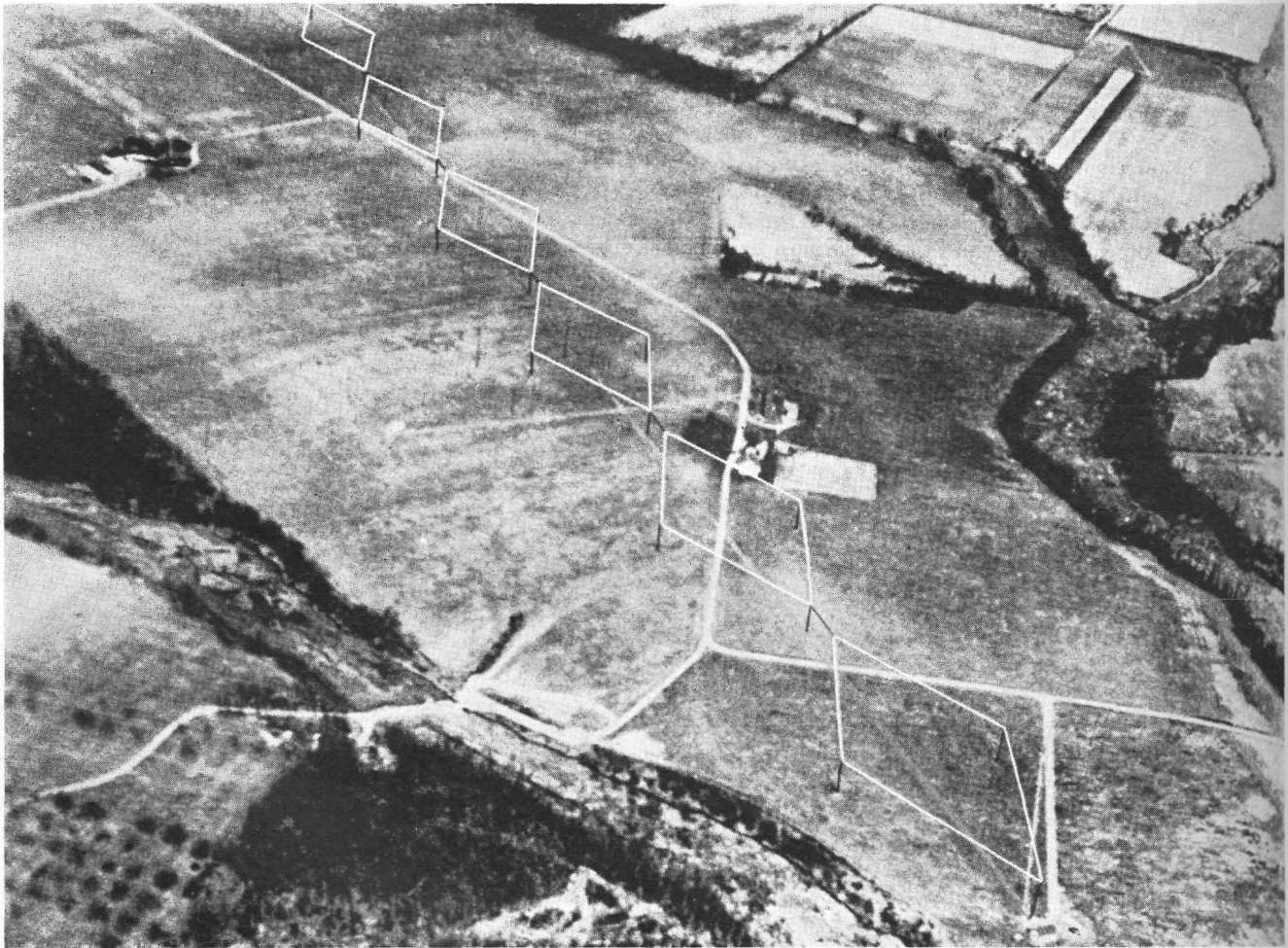
the frequency used, so that the wave may arrive in the fewest possible jumps. For comparatively short distance communication (between 100 and 400 miles), the optimum angle of radiation will be considerably higher, but because very high frequency waves are not readily bent, and penetrate the ionosphere when striking it at too steep an angle, we see that the shorter wavelengths are not satisfactory for short distance communication. Thus, we have the skip distance, or zone of silence, previously referred to.

Recent developments in antenna systems have done much to reduce the bad effects of the ionosphere. Outstanding in this phase is the system devised by H. T. Friis and C. B. Feldman of the Bell Laboratories. Its effectiveness is due to the use of directional rhombic antennas and to an assembly which affords "steerable" directivity. The system is arranged to have a very sharp directivity in a vertical plane, and is provided

with means whereby the angle of maximum effectiveness in the vertical plane can be adjusted so as to coincide with the angle of arrival of the radio waves. Antennas of this type have been referred to as Musa systems, from the first letters of the words in the phrase "multiple unit steerable antenna."

The Musa antenna system consists of a number of rhombic antennas, uniformly spaced along a line. The vertical directivity of each of the several channels derived from the system is individually steerable. One of these channels is set for the vertical angle corresponding to the best reception at the moment; another, at the angle for second best reception etc., while one is reserved for exploring the conditions at different angles and for monitoring. The outputs of the separate channels are combined after detection, with sufficient phase delay inserted in the lower angle channels so that the envelopes of all the channels will be in the same phase when added. If three channels are added, there is practically never a time

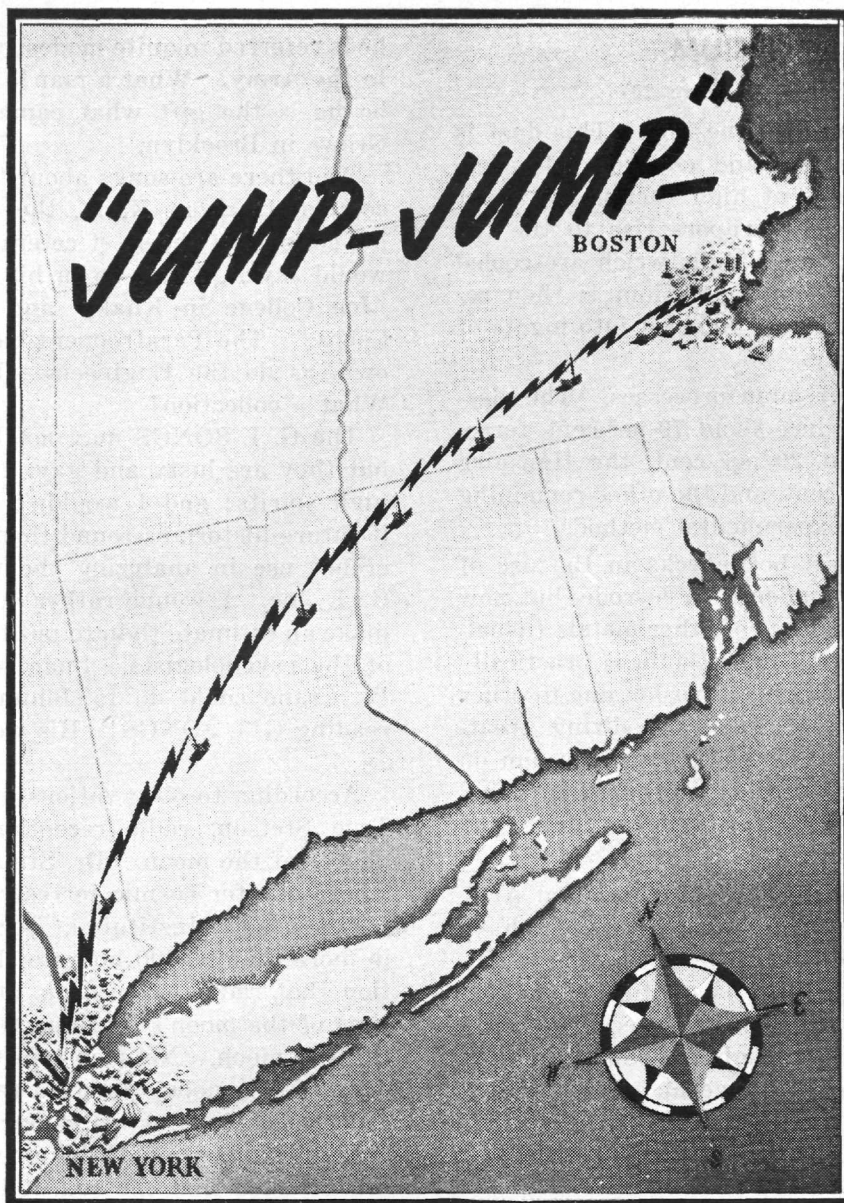
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—Photo reproduced courtesy Bell Telephone Laboratories.

**Aerial view of Musa system located near Holmdel, N.J. The six antennas extend  $\frac{3}{4}$  mile along the direction of the great circle through England**





## NEW RADIO RELAY LINK FOR TELEPHONE AND TELEVISION

Tiny radio waves, shorter than any used before in commercial telephony, will link New York and Boston in a new experimental "jump-jump" relay system for the transmission of telephone speech and television programs.

These waves travel in straight lines like beams of light. Because of the earth's curvature, the distance will be spanned in a series of straight-line jumps between transmitting and receiving stations about 30 miles apart.

The Bell System plans post-war improvements in ways like this, to extend its nation-wide service by providing more Long Distance telephone facilities for peacetime needs.

## BELL TELEPHONE SYSTEM

*"Service to the Nation in Peace and War"*



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## IONOSPHERE

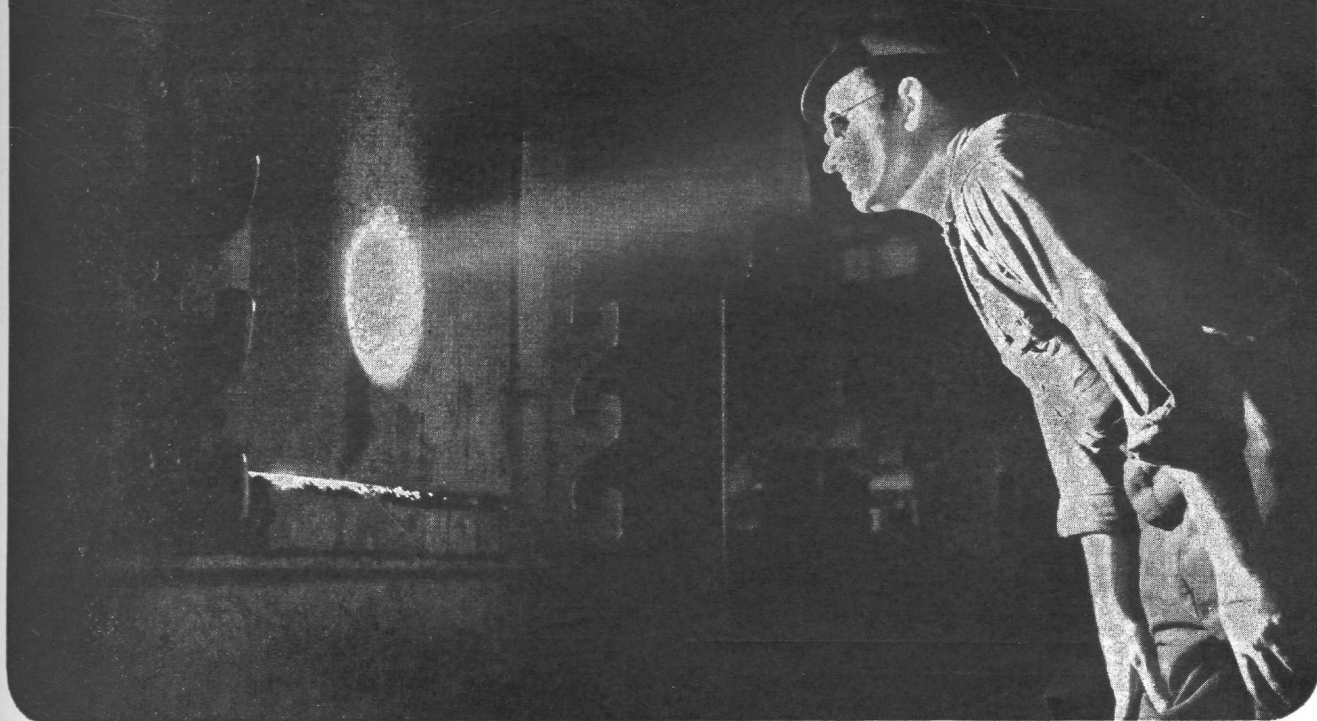
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when at least one will not be above the noise level, thus giving full diversity. The phasing is accomplished by means of adjustable phase shifters that are interconnected so that they can be operated from a single control.

The Musa receiving system is the most effective arrangement that has ever been devised for the reception of short-wave signals. It not only eliminates fading but also avoids most of the quality distortion associated with ordinary fading. Furthermore, the use of directivity steering makes it possible to employ much greater vertical directivity than would otherwise be permissible. In the most elaborate installation of this type that has been made, the improvement in signal-to-noise ratio resulting from the added vertical directivity is 12 decibels over the ratio for a single directional antenna.

Thus we see that although not everything is completely known about the ionosphere, scientists have been able to overcome and utilize the effects of the ionosphere to the advantage of man. More facts concerning the ionosphere and troposphere may yet be uncovered and lead to new phases of wireless communication.

# THERE'S SUCH A THING AS MAKING A SCIENCE OF PEEPING



OWI by Palmer, in an Allegheny Ludlum Plant.

**W**ITH this melter, studying the action of some 35 tons of alloy steel in an Allegheny Ludlum electric furnace, peeping is resolved into a science.

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hold. Buying bonds, conserving food, fuel, gasoline, rubber, waste fats and scrap metal—all these have to do with how soon the war will be won, and at what price. They are *everyone's* jobs. Have you done—are you doing—all you can?



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